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21 - 25 September 1998

Trieste, Italy

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Abstracts

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INTERNATIONAL WORKSHOP ON THE 'OCEANOGRAPY OF THE ADRIATIC SEA"

21 - 25 September 1998

All sessions/lectures were held at the SISSA Building - Next to the ICTP Main Building

Monday, 21 September	Tuesday, 22 September	Wednesday, 23 September	Thursday, 24 September	Friday, 25 September
Tribute to Zore-Armanda	**New Physical Observations and Instrumentation**	**Modeling (comprehensive)**	**Deep Water Formation & Climate Variability**	**Workshop**
All Sessions on this day ONLY will be held at the SISSA Main Lecture Hall Chair: M. Gacic	Chair: P.-M. Poulain *All Sessions will be held at the ICTP Main Bldg. - T-Level*	Chair: R. Mosetti	Chair: A. Lascaratos	
9:00-9:45 Registration (ICTP Main Building - Lobby)	9:00-9:20 L. Ursella & J. Candela	**9:00-9:45 N. Pinardi, M. Zavatarelli, A. Maggiore & C. Cesarini**	**9:00-9:40 P. Malanotte-Rizzoli & B. Manca**	9:00-10:00 Round Table Introductory Comments T. Legovic G. Civitarese & M. Ribera
9:45-10:00 Furlan, Nicolich, Poulain, Cushman-Roisin: Welcome Remarks	9:20-9:40 H. Perkins & P. Pistek	**9:45-10:30 C. Naimie & B. Cushman-Roisin**	9:40-10:00 V. Cardin, V. Kovacevic & M. Gacic	
10:00-10:15 M. Gacic Tribute to Mira Zore-Armanda	9:40-10:00 J. M. Stevenson	10:30-10:50 C. Horton, M. Clifford & J. Schmitz	10:00-10:20 B. Rajkovic	
			10:20-10:40 B. Manca & V. Kovacevic	
10:15-11:00 **M. Zore-Armanda**	10:00-10:20 J. Sellschopp, H.-V. Fiekas, S. Podewi & K. Herbig	*10:50-11:20 Break*	*10:40-11:05 Break*	*10:00-10:30 Break*
	10:20-10:40 F. Dallaporta	**11:20-12:05 D. Dietrich, S. Piacsek, G. Ficca & R. Purini**	**11:05-11:45 M. Morovic & B. Grbec**	10:30-12:30 Round Table Adriatic Sea: Physical & Biological System
11:00-11:45 **I. Ovchinnikov, V. Krivosheya, Y. Popov & Y. Lukashev**	*10:40-11:00 Break*		11:45-12:05 A. Giorgetti & B. Manca	
	Biogeochemical Aspects Chair: I. Marasovic	12:05-12:25 G. Carnevale, F. Crisciani, S. Llewellyn Smith & P. Orlandi, S. Piacsek, R. Purini, F. Raicich & R. Serravall	12:05-12:25 J. Sellschopp	
11:45-12:30 A. Artegiani, E. Paschini & A. Russo	**11:00-11:45 T. Hopkins**	12:25-12:45 P. Lionello & P. Malguzzie	12:25-12:45 G. Cini Castagnolo, G. Bonino, P. Della Monica & C. Tarico	
	11:45-12:30 G. Civitarese			
	12:30-12:45 E. Souvermezoglou & E. Krasakopoulou			
12:30-2:00 Lunch	*12:45-2:00 Lunch*	*12:45-2:00 Lunch*	*12:45-2:00 Lunch*	*12:30-2:00 Lunch*
New Physical Observations and Instrumentation	**Biogeochemical Aspects**	**Modeling (specific)**	**Regional Oceanography**	**Workshop**
Chair: P-M. Poulain	Chair: T. Hopkins	Chair: N. Pinardi	Chair: M. Orlic	
2:00-2:45 V. Barale	**2:00-2:45 I. Marasovic**	**2:00-2:45 C. J. Lozano, A. R. Robinson & A. Russo**	**2:00-2:45 M. Gacic**	2:00-4:00 Discussion in Groups: Interannual & Seasonal Variability & Climate Change, Ecosystem Functioning/Modeling Coupling with Mediterranean/Otranto Wind Forcing. Data Assimilation
2:45-3:05 R. Santoleri, S. Marullo, F. D'Ortenzio & S. Zoffoli	**2:45-3:30 M. Ribera**	**2:45-3:30 V. Malacic**	**2:45-3:30 M. Orlic**	
3:05-3:25 F. Vitiello, F. Borfecchia, S. Cagnetti, L. De Cecco & S. Martini	**3:30-4:15 W. Helder**			
3:25-3:55 Break	*4:15-4:40 Break*	*3:30-4:00 Break*	*3:30-4:00 Break*	*4:00-4:30 Break*
3:55-4:40 P.-M. Poulain	4:40-5:00 M. Giani, A. Boldrin, G. Matteucci, A. Cessari, F. Frascari, M. Gismondi & S. Rabitti	**4:00-4:45 A. Lascaratos & A. Mantziafou**	4:00-4:20 A. Russo, A. Artegiani, M. Galassi, M. Marini, E. Paschini, N. Pinardi, M. Zavatarelli, F. Raicich, A. R. Robinson & C. J. Lozano	4:30-6:00 Final Report
	5:00-5:20 F. Frascari, M. Frignani, M. Ravaioli, F. Alvisi, M. Marcaccio, G. Matteucci & C. Bergamini	4:45-5:05 M. Zavatarelli	4:20-4:40 I. Vilibic, N. Leder, & A. Smircic	
4:40-5:00 E. Mauri, P.-M. Poulain & M. Gacic	5:20-5:40 S. Albertazzi, F. Alvisi, S. Albertazzi, M. Fragnani, L. Langone, M. Ravaioli & D. Sorgente	5:05-5:25 G. Umgiesser, C. Solidoro, G. Crispi & A. Crise	4:40-5:00 G. Panza	
5:00-5:20 A. Griffa, P.-M. Poulain and E. Zambianchi	A. Boldrin, M. Giani- C. Salvi (POSTER)	5:25-5:45 V. Kourafalou	5:00-5:20 F. Raicich	
5:20-5:40 G. Lacorata, E. Aurell & A. Vulpiani		5:45-6:05 S. Dobricic & W. Eifler	5:20-5:40 F. Stravisi	
			5:40:6:00 F. Stravisi & N. Purga	
6:00 ICTP Reception - ICTP Main Building - T Level		7:30 Workshop Banquet San Giusto Castle		

Monday, 21 September

Session:

New Physical Observations & Instrumentation - I

Tribute to Mira Zore-Armanda

M. Gacic

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Mira Zore-Armanda has conducted oceanographic research on the Adriatic Sea for almost half a century. Most of the papers on the Adriatic Sea physical oceanography published in the last twenty years have at least one reference to Zore-Armanda's work. During this long period, she has been studying almost all aspects of the Adriatic oceanographic characteristics from evaporation measurements, seiches, seasonal sea-level variations, coastal oceanography and basin-wide geostrophic circulation. Moreover she has been very active in Adriatic multidisciplinary studies. She was the first to estimate the water and nutrient exchange rates between the Adriatic and Ionian Seas and headed a team that tried to explain the long-term variability of the primary and secondary production in terms of climatic conditions. Since the very beginning she understood the importance of climatic changes and has put a lot of efforts in setting up a permanent Middle Adriatic oceanographic monitoring system. Her pioneering work on teleconnections has not received deserved attention but nevertheless she was one of the first scientists trying to explain long-term changes in the Mediterranean in terms of the continent-wide climatic conditions. More than twenty years before the North Atlantic Oscillation index has received wider attention, she tried to correlate the quantity of ice at the North Pole with the oceanographic conditions in the Adriatic and Mediterranean as well as to compare the north-south atmospheric pressure gradient (Trieste - Athens) with the inflow of the Ionian waters into the Adriatic. In fact in one of her papers she concluded that "*the quantity of ice in the North Atlantic exercises a certain influence upon the oceanographic characteristics of the Adriatic. Moreover it appears that this (quantity of ice) can be related to the properties of the baric field over the North Atlantic, Europe and Mediterranean, as well as a very dry and cold wind over the Adriatic or more frequent and stronger northerly winds* ". In this way Mira Zore-Armanda is not only a founder of the modern Adriatic oceanography but has also contributed appreciably in explaining some global oceanographic aspects.

History of Adriatic Oceanography and Overview of Hydrography

M. Zore-Armanda

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This historical overview covers a century of research - the period between the eighteen-eighties and the nineteen-eighties.

Before WW1 research was broad and based on intensive data collecting during maritime expeditions. Research performed in the period between the two world wars was more narrowly focused on the northern Adriatic and mid-Dalmatian regions.

Since the nineteen-fifties the Adriatic was again studied as a whole. More expeditions were organized. Seasonal and multi-year fluctuations in various phenomena were examined. Properties of water masses were defined. The basic objective was the development of phenomenological models, to be also applied to biological research. Causes of various phenomena were sought, especially those regarding certain dynamical processes.

With the onset of our awareness of the sea pollution problems, the Adriatic oceanography is currently being re-oriented again toward the more vulnerable coastal zones. As much international work is being done, large data bases are being assembled, and coastal dynamics and hydrology are better understood.

Winter Hydrological Conditions in the Adriatic Sea and Water Exchange Through the Otranto Strait: Results of Soviet Research during 1959-1990

I. M. Ovchinnikov, V. G. Krivosheya, Y. I. Popov and Y. F. Lukashev

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Soviet oceanographic investigations of the Mediterranean Sea, which began with studies of the Eastern Mediterranean in 1959, first sought to ascertain where and how the vast mass of its deep waters is formed. As it is known, Pollak was the first to point out in 1951 that the deep waters of the central and eastern basins of the Mediterranean Sea have an Adriatic origin. It was supposed that the Deep Adriatic Waters (DAW) is a result of mixing between the surface waters of the Adriatic Sea and the Levantine Intermediate Waters (LIW) in proportion 7:1. But as to the location of DAW formation, there was no single opinion and conjectures ranged from the northern shelf to the Otranto Strait. Therefore, vigorous searches of DAW formation foci were undertaken (Ovchinnikov et al., 1978, 1985 and 1990), during which we successfully used the method of deep convection earlier applied in the course of the MEDOC-69 experiment (MEDOC Group, 1970):

1. In mid February 1977 the results of cruises by R/Vs "Professor Vodyanitsky" and "Academic Petrovsky" located "the preconditioning phase" of DAW formation in the center of the Southern Adriatic Pit. Within this phase a cold subsurface interlayer is formed which is peculiar to all the northern cyclonic gyres in the winter period.

2. In early March 1982, a cruise of R/V "Professor Vodyanitsky" found out "a violent mixing phase" of the cold and less saline surface waters with the warmer and more saline LIW. In this case, the convection developed to the depth of 800-850 m. Then, in the course of studies aboard the r/v "Yakov Gakkel" in the Southern Adriatic in early March 1990, certain distinct signs of the DAW formation to the depth of 600-700 m were discovered north of the Otranto Strait.

3. In early April 1977, observations aboard R?V "Professor Bogorov" in the southern part of the Adriatic revealed under the upper stratified 100 m layer "the sinking and spreading phase" of the DAW with a density of 29.20-29.50, covering the layer from 300 to 1000 m.

In this manner the DAW, being formed above the level of the Otranto sill, overflows into the Ionian Sea and sinks there down to 2000-2500 m depth thus being the origin for the deep waters of the Eastern Mediterranean. It is also to be noted that in the middle Adriatic, over the Jabuka Pit occasionally (200 m depth), very dense waters (up to 29.60) are formed. These accumulate in the pit and then overflow into the southern pit where they form dense near-bottom waters

(29.25-29.30). As a rule, these waters do not overflow into the Ionian Sea over the Otranto sill.

As it was shown by our winter measurements (in 1957-56, 1960 and 1962 (a); in March 1982 (b); and in April 1977 (c)), the current structure in the Otranto Strait represents a bilateral water transport southwards and northwards, with the interface having a slight slope to the west. The lower part of the southward transport (on the west side of the strait) beginning at depths of 400-500 m represents the outward transport of DAW. Its velocity is rather variable (ranging from 10 to 50 cm/s), causing the transport to undergo strong changes (from 0.2 x106 to 1.8 x106 m3/s). The cause of this variability probably lies in changing winter climatic conditions over the Adriatic Sea basin. Our conclusions concerning the DAW formation in the southern Adriatic are well confirmed by modern investigations according to the data of 1996 (Manca, Bregant, 1998). The large variability of DAW transport by the lower current on the west side of the Otranto Strait has also been confirmed by Gacic et al. (1996).

Hydrology and Climatology of the Adriatic Sea

A. Artegiani, E. Paschini and A. Russo

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The Adriatic Sea, an Eastern Mediterranean sub-basin, has interested the oceanographic research world from a long time ago. Buljan and Zore Armanda report in their monography (1976) on the Adriatic Sea that already in 1528 Frederic Grisogono from Zadar published a book on the Adriatic Sea tides. However the first oceanographic cruises were carried out during the second half of the 18th century.

In 1982, IRPEM, in collaboration with the Institute of Oceanography and Fisheries of Split, began to collect on computer format historical oceanographic data of the Adriatic Sea, obtaining after several years a data set named ATOS1 (Adriatic Temperature Oxygen Salinity data set 1). ATOS1 comprises 5543 "open sea" stations (stations with a bottom depth less than 15 m or located inside the Dalmatian channels area have been excluded) performed from 1911 until 1983. Temperature measurements are included in 5518 stations, salinity in 5503 and dissolved oxygen in 2673.

The most part of the data (about 90%) were collected by "manual" means, i.e. temperature has been measured by means of reversing thermometers, salinity by means of Mohr-Knudsen titration method or by laboratory salinometers, dissolved oxygen by means of Winkler method. It has been realized also another data set for the biogeochemical parameters, named ABCD1 (Adriatic BiogeoChemical Dataset 1).

These two data set permitted to describe for the first time the physical and biogeochemical climatology of the Adriatic water masses (Artegiani et al., 1997; Zavatarelli et al., in press). In this communication we will deal with physical oceanography only. We define the climatologic water masses of the three sub-basin in which we divide the Adriatic Sea and the freshwater balance for the whole basin; with geostrophic calculations, we derive also the baroclinic structure of the Adriatic Sea general circulation.

Examining the distribution of the stations, it is evident that the scientific investigation focused on the Northern Adriatic, with some interest for the Middle Adriatic, while the Southern Adriatic received scarce attention at least until the eighties. Moreover, for what concern the biogeochemical parameters, data are scarce for the whole Adriatic basin.

Both data sets are not complete, because some published data sets could be still not included in them and data from many oceanographic cruises have never been published. However, we can suppose that adding other historical data to ATOS1, results should not be remarkably different, except if a large number of stations were added in the Southern Adriatic. More attention, instead, should to be paid to the realization of ATOS10, a data set formed by the CTD casts performed by the eighties to present, and we are working in this direction.

In fact, during the last years the Adriatic Sea has received a renewed attention by the Italian and international scientific community. This is firstly due to the massive rise of mucilaginous substances registered in these last years with higher frequency than in the past, and secondly to the relevance of the Adriatic Sea for what concerns tourism and fishery (about 63% of the total Italian catches comes from the Adriatic Sea).

A number of projects received funds from the European Community in the frameworks of the MAST (MERMAIDS1 and 2, EUROMARGE AS, OTRANTO, etc.) and Environment (ELNA, PALOMA, MARE, EUMAC, etc.) programs. The Italian Government funded specific projects on the Adriatic Sea, as PRISMA. The Second Phase of the PRISMA project is still being carried out, and activity and preliminary results of the sub-project 1 (Physical, Chemical and Biological Oceanography) will be showed.

Adriatic Sea Environmental Features and Trends in the Historical Surface Pigment and Temperature Fields

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The compilation of historical time series of remotely sensed data, collected in the visible and infrared spectral ranges, has pointed out, for the first time, the geographical provinces of the Mediterranean Sea and its semi-enclosed water bodies, characterized by specific environmental features and trends. Long-term statistics of the optical and thermal fields, derived from the existing Coastal Zone Color Scanner (CZCS) and Advanced Very High Resolution Radiometer (AVHRR) time series, have been used to explore the space/time distribution of water parameters at the basin scale, and in the Adriatic Sea in particular. Contrary to geographic subdivisions commonly adopted, mean annual pigment concentrations and surface temperatures qualify the Adriatic Sea as one of the western sub-basins - with the transition between western and the eastern Mediterranean regimes corresponding to the line of narrow straits going from the Sicily Channel, to the Strait of Messina and the Strait of Otranto.

In general, in the annual means, the western regime is characterized by higher pigment concentrations and lower temperatures than the eastern one. The data show similarities in the dynamics of both parameters in the Adriatic and in the Ligurian, Provençal and Balearic sub-basins - and in the northern Aegean Sea, up to a point. This suggests that the environmental features of the Adriatic might be shaped by the same factors influencing the rim of marginal sub-basins around the northern Mediterranean arc, characterized by important orography, with a wet climate for at least part of the year, by rivers (e.g. the Po) draining large watersheds, and by major winds (e.g. the Bora) responsible for deep water formation at various near-coastal sites.

In the time domain, the general characteristics of the pigment and temperature fields are rather constant for the whole mediterranean, while differences occur only in the details composing the larger picture. Seasonal variations are most pronounced in the western rather than in the eastern sub-basins, with lower temperatures and higher concentrations in late winter and early spring. This would point to a (biogeochemical) behavior similar to that of "sub-tropical" seas, where light is never a limiting factor, but nutrients always are. In such a scenario, the maximum in surface pigments would occur in the cold season, when the rains come to the region, coupled to maximum runoff, surface cooling and vertical mixing - as opposed to a minimum in the warm and dry season, when the water column is strongly stratified and no nutrient supply (from coastal zones or deeper layers) is

readily available. While most of the basin seems to follow this general model, specific areas present also different characteristics (e.g. the Ligurian-Provençal and Adriatic sub-basins). Notably, the Adriatic Sea can present anomalous high concentrations of water constituents in summer, associated with the impact of runoff from continental margins (i.e. both a direct impact due to the sediment load and one induced on the planktonic flora by the associated nutrient load), and with the surface circulation patterns typical of this seasonal condition.

Seasonal and Interannual Variability of the Sea Surface Temperature Structure in the Adriatic Sea

R. Santoleri[1], S. Marullo[2], F. D'Ortenzio[1] and S. Zoffoli[1]

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Seasonal and interannual variability of the sea surface temperature field in the Adriatic Sea is analyzed using a nine years time series of daily AVHRR (Advanced Very High Resolution Radiometer) data. The data used are the 9 km resolution sea surface temperature maps obtained in the framework of the Pathfinder project. This spatial resolution allowed analysis of only basin and sub-basin scale features. Average monthly sea surface temperature maps for the entire studied period (1987-1995) are discussed.

The analysis shows the absence of any permanent surface SST feature in the Adriatic Sea. The cyclonic circulation of the south Adriatic Sea is marked by a surface temperature minimum that recurrently appears in late autumn or early winter, i.e. in the preconditioning and deep water formation phase. This however, does not preclude completely the permanent nature of the gyre since it can be controlled by the salinity distribution as well.

During autumn the surface inflow of Ionian water is observed while the Adriatic outflow is more evident in winter. The occurrence of this prominent warm water plume along the eastern coast in autumn is in a god agreement with findings from direct current measurement in the Otranto Strait that suggests that the Ionian waters inflow reaches its maximum in autumn.

Results of an EOF analysis suggest that the intensity of the western coastal cold water plume and the north Adriatic thermal front vary from year to year. Other sub-basin features like the south Adriatic gyre also display year-to-year variability.

A subsequent analysis done using full resolution AVHRR images (1.1 km) of the last three years confirms the results of the coarse resolution data and add more information on the variable mesoscale field of the Adriatic Sea.

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Remote Sensing and Adriatic Sea Circulation

F. Vitiello, F. Borfecchia, S. Cagnetti, L. De Cecco and S. Martini

ENEA, Rome, Italy

The paper shows some of the results of ENEA research activities on Adriatic Sea, based on satellite remote sensing. The activities were requested by the Italian Research Ministry to gain knowledge of environmental conditions of the Adriatic Sea and were carried out by various Italian Research Institutions as ENEA (Italian National Agency for New Technology, Energy and the Environment), CNR (National Research Council), ICRAM (Marine Environment Research Council) and ISS (National Health Institute).

In this work ENEA used NOAA-AVHRR and NIMBUS-CZCS multispectral images. Thematic maps of sediment distribution were obtained via calibration and processing of NOAA data; chlorophyll concentration maps were derived from CZCS data.

The processed satellite images covered the period from 1980 to 1996. The processing of remotely sensing images allowed to detect and classify typical circulation situations of the sea depending on seasonal period. Some results of the work are available in an internet web site.

Twenty Years of Lagrangian Measurements in the Adriatic Sea: A Review

P.-M. Poulain

Naval Postgraduate School, Monterey, California, USA

Surface and subsurface currents and water properties such as temperature can be measured by means of freely drifting devices, from simple bottles or computer cards to sophisticated instrumented drifters and floats tracked by satellite. The main advantage of this Lagrangian measurement technique is the global sampling, both in time and space, of the multi-scale variability of the property or velocity fields, given repeated optimized deployments of drifting instruments in the basin of interest. The Lagrangian observations collected in the Adriatic from the late 1970's to present are reviewed and interpreted in this talk.

Lagrangian observations of the surface circulation in the Adriatic started with drift card experiments conducted from 1979 to 1986 (Ferencak et al., 1982; Morovic et al., 1997). The total card displacements between their release sites and where they were found along the coast, provided some information on the probable courses of surface water particles as well as on the surface current direction for the four seasons of the year. Results were in good agreement with velocities inferred from density gradients and with other moored direct current measurements, although direct surface wind effects were obviously partially responsible for the card drifts.

A first attempt to measure the surface currents in the northern Adriatic using satellite-tracking technology was made by Borzelli et al. (1992) using five undrogued drifting buoys. Objectively analyzed velocity and kinetic-energy fields obtained from this limited data set showed the typical double eddy circulation regime off the Po River delta in late summer 1990.

As part of military survey operations, surface satellite-tracked drifters were deployed intermittently in the Adriatic between 1989 and 1998. These data have been combined to two extensive drifter data sets covering the period winter 1995 - spring 1998 in order to describe the spatial characteristics and the temporal variability (mesoscale to seasonal/interannual) of the Adriatic surface circulation. The first data set (December 1994 to March 1996) comprised more than 60 drifters principally released in the eastern side of the Strait of Otranto. This study was particularly focused on the surface circulation in the southern Adriatic and on the Albanian shelf. The second data set is more recent (August 1997 - June 1998) and the release strategy was different. The drifters were deployed on a seasonal basis throughout the basin in order to maintain a minimum drifter population in the entire Adriatic for about a year. In this way, the seasonality of the global circulation could be addressed more accurately. In

addition, the response of the surface currents to the wind forcing (at synoptic and seasonal scales) was a main focus. A few drifters were instrumented with a vane of the surface buoy and a surface hydrophone so as to obtain in-situ wind direction and speed measurements, respectively. The main results obtained from these surface drifter data sets are:

1) The mean surface circulation in the Adriatic Sea consists of a basin-wide cyclonic gyre with north/northwestward prevailing currents on the eastern side and south/southeastern return mean flow on the western side. This mean pattern extends as far north as 44.5°N. North of this latitude the drifters showed an isolated cyclonic loop near the northern end of the Adriatic Sea. Smaller, sub-basin cyclonic circulation features controlled by the topography of the central (Jabuka Pit) and the southern (SAP) Adriatic are embedded in the global gyre. First, strong currents (speed superior to 40 cm s-1) are found in both the eastern and western coastal areas. Second, the paucity of drifter observations in specific zones shows the possible existence of horizontal flow divergence. Other zones were identified in which the drifters tend to slow down and accumulate. These might be the site of horizontal convergence. We can speculate that these localized zones of convergence or divergence could be preferential sites for the deep Adriatic water formation.

2) Sub-tidal fluctuations around the above mean circulation scheme can be quite substantial, especially where the mean currents are strong. They have a tendency to be oriented in the same direction as the mean flow because the bathymetry or the proximity of the coast prevents cross-shore variations. The velocity standard deviation of the fluctuations can be as large as the mean. Part of the variations can be attributed to local wind events that can, if they are strong enough, create flow reversals. Velocity variations can also be associated with changes in the buoyancy input (density forcing) from river runoffs, such as the Po River in the northern Adriatic (Malanotte-Rizzoli and Bergamasco, 1983). Another cause could be mesoscale features such as eddies, jets and filaments formed by baroclinic instabilities of the mean flow. If the seasonal cycle is not resolved separately, then it can represent a substantial portion of the velocity fluctuation energy related to the seasonal variability of the atmospheric (wind) and buoyancy (rivers) forcings.

3) Seasonal variability was explored in the southern Adriatic and the Strait of Otranto region. The enhanced horizontal shear in the Strait of Otranto in winter, with maximum ingoing Ionian water near the eastern flank and maximum outflowing Adriatic water on the western side, associated with the increased cyclonic circulation around the SAP, corroborates the hydrographic and moored observations of Zore (1956) and recent surface thermal analyses of seasonal variability in the southern Adriatic using satellite imagery (Gacic et al., 1997). In summer, broad outgoing currents dominate on the Italian shelf which agrees with previous studies (Zore, 1956; Orlic et al., 1992). The spring situation is

characterized by reduced surface transport in the central and eastern parts of the Strait of Otranto. The currents are moderate, chaotic and either dominated by mesoscale features formed by baroclinic instability of the mean flow or associated with coastal upwelling episodes along the Albanian coast (Bergamasco and Gacic, 1996). In fall, the cyclonic circulation around the SAP is still intense with strong currents on the Italian shelf, but the transport across the Strait of Otranto appears to be reduced.

A first attempt to use subsurface floats to track the intermediate currents was made with two P-ALACE systems in the Southern Adriatic and the Strait of Otranto areas between May 1995 and December 1996. The P-ALACEs were programmed to execute the following repetitive cycle: dive to a depth of about 300 m (core of the Modified Levantine Intermediate Water) where they became neutrally buoyant and drifted with the currents for 2 days and then ascended to the surface, while sampling the temperature profile, where they were tracked by and telemetered data to the satellite Argos system. Besides the technological success of using autonomous Lagrangian profilers in shallow, constricted coastal environments, the drift (velocity) and temperature data collected are quite interesting. They show the barotropic character of the circulation in winter and delineated clearly the seasonal evolution of the mixed layer and the thermocline.

Surface circulation of the Adriatic Sea from satellite and Lagrangian data: Preliminary results

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The spatial characteristics and the temporal variability of the surface circulation in the Adriatic Sea are explored using contemporaneous remotely sensed and Lagrangian measurements between September 1997 and July 1998.

Over 80 SeaWiFS images were processed (using SeaDAS) to produce color-coded chlorophyll-a concentration maps whenever the cloud cover over the Adriatic was inferior to about 50%. For the days in which SeaWiFS data were processed, AVHRR MCSST daily composite images were obtained from the German Space Agency (DLR). The data from more than 60 satellite-tracked surface drifters were used to complement the satellite ocean color and thermal measurements.

Assuming that the chlorophyll-a content and the temperature of the surface waters can be considered as passive tracers that are advected by the currents, the satellite maps provide some clues about the structure and variability of the surface circulation from the mesocale to the seasonal scale. Drifter trajectory segments overlaid on the satellite images add quantitative information on the horizontal displacements (speed and direction) of the various water mass encountered.

Given the enhanced gradients in pigment concentration and in surface temperature, especially those associated with the fresh water discharge from the Po River, the satellite maps are optimal tools to describe many dynamical features in the Adriatic Sea. These include the southeastward coastal current along the Italian Peninsula and its associated instabilities, the double vortex circulation in the northern part of the basin which, in winter, is forced by strong events of Bora winds, and the northwest flow along Albania influenced by the buoyancy input from river runoff and dominated by mesoscale instabilities. The above features and the seasonal variation of the circulation patterns are well described by our combined satellite-Lagrangian data sets.

Estimates of Transport Parameters From Lagrangian Data in the Adriatic Sea.

A. Griffa[1], P.-M. Poulain[2] and E. Zambianchi[3]

[1]CNR, La Spezia, Italy and RSMAS, University of Miami , Florida, USA
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[3]I.U.N., Naples, Italy

A data set of drifter trajectories in the Adriatic Sea (Poulain et al. 1996, Poulain 1998) is used to characterize transport properties in the period between December 1994 and March 1996. Three main aspects are considered.

1) The transport properties at the scale of the basin are studied, with special interest toward exchange between northern and southern basins and between coastal and deep sea regions. The effectiveness of topography constraints and the effects of potential vorticity conservation versus direct forcing are studied.

2) The transport due to the turbulent eddy field is considered in detail. A decomposition between large scale mean field and turbulent velocity is first performed, using a technique based on energy minimization in the turbulence at low frequencies (Bauer et al., 1998). The turbulence transport is then characterized in terms of diffusivity, turbulent energy and time scales.

3) The integral properties describing the spreading and the transport of particles (or tracers) released in specific regions are studied. Special interest is given to releases in the Strait of Otranto, where more than half of the drifters have been deployed. Quantities such as the total concentration and the average time spent by a particle in the Adriatic basin (residence time) are computed. A comparison is performed between measured quantities and theoretical estimates obtained for idealized basins (Bellucci et al., 1998).

Data Analysis and Modeling of Lagrangian Tracers in the Adriatic Sea

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Lagrangian data offer the opportunity to employ techniques of analysis, well established in the theory of chaotic dynamical systems, to study the transport properties of actual trajectories and compare those with a kinematic model. Considering the standard diffusion coefficient may not be very helpful, in case of closed basins, because the asymptotic regime is not approached before finite scale effects set in. Other quantities like the Finite Size Lyapunov Exponents, on the other hand, can provide clearer informations on the mean divergence rate of two initially close trajectories over a range of spatial scales.

Tuesday, 22 September

Sessions:

New Physical Observations & Instrumentation - II

Biochemical Aspects

Normal Barotropic Modes of the Adriatic Sea and Their Use in the Analysis ofShipboard ADCP Observations

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[2]CICESE , Ensenada, Mexico

In order to analyze ADCP data and to separate the different contributions (e.g., the tidal part and the steady term) in the signal, the construction of a proper basis of functions for the system is needed. One such basis of functions is given by the normal barotropic modes, which are the natural oscillations of the basin in the absence of external forcings. Each of the terms of the velocity can then be written as a linear combination of these functions, and fitted to the observed data. In the present work, a spectral model, developed by Candela and Lozano (1994) for the Mediterranean Sea, is extended by including explicit boundary functions and applied to the Adriatic Sea. A spectral representation of the system of equations is used, expressing the vertically-averaged horizontal velocity in terms of the Helmholtz-Proudman potentials. The system of equations reduces to an eigenvalue problem, from which a complete ortho-normalized set of functions for the basin is obtained. It is important to note that even if the forced response of the basin (e.g., for the tidal signal) presents a structure different from any of the normal modes, the response is expected to be resonant if either the spatial structure of the forcing or its time variability matches the corresponding structure for one or more of the normal modes. In this work we show the spectrum of the barotropic normal modes of the Adriatic Sea, analyzing which of these modes are mainly involved in the response of the sea to the tidal forcing. Then, a subset of the normal modes is used in the analysis of shipboard ADCP observations and the results are compared with analyses done using other arbitrary basis functions.

The Prospect for Data Assimilation in the Adriatic Sea

H. Perkins and P. Pistek

Naval Research Laboratory
Stennis Space Center, MS, USA

Barotropic data assimilation has proved very successful in the Yellow Sea. That is, we have been able to find solutions to the vertically integrated shallow water equations of motion that are an optimum least-squares fit to all available data, and the agreement is very close. As a result, good estimates of tidal height and current are now available throughout most of the Yellow Sea. In this presentation, we describe the conditions that make such a result possible and consider the extent to which they would apply in the Adriatic Sea. Key factors are basin width as measured by the barotropic deformation radius and the relative importance of wind and tidal forcing. We conclude that the Adriatic is a very attractive site for application of assimilation methodology. Moreover, we present evidence that assimilation of real-time data, even using the present simplified dynamics, could provide the basis for accurate short-term forecasts of surface height and coastal currents.

In-Situ Sensing Technology for Shallow-Water Oceanography

J. M. Stevenson

Space and Naval Warfare Systems Center, Acoustic Branch
San Diego, California, USA

Recent technological developments in sensing and communications allow field oceanographers to obtain synoptic mesoscale in-situ ocean observations with spatial and temporal resolution that was previously often unaffordable.

Here one such example, a novel vertical line array (VLA) of relatively inexpensive oceanographic sensors, is described.

The intent of this device is to provide oceanographers with a low-cost, moderate-resolution sensor suite that affordably yields dense spatial sampling for a period of roughly one week in shallow-water applications, particularly in the context of monitoring fast-moving oceanographic events. Some of the sensors are adapted for oceanic use from other intended commercial applications (e.g., automobiles, factory assembly line monitoring, medical instrumentation), others are new developments. The system would not replace existing high-resolution oceanographic instrumentation, but fill the niche for a low-cost, lower-resolution system that would provide the end user with the ability to achieve higher spatial sampling. The working hypothesis that motivated this work is the concept that an array of low-cost, lightweight expendable COTS sensors utilizing proven time division electrical multiplexing can provide a robust, affordable data collection apparatus for environmental sensing.

The described system, called the Autonomous Buoyed Environmental Measurement System (ABES), is an integrated suite of oceanographic sensors that communicate on a single wire conductor to a buoy-based memory and RF (radio frequency) communications device.

The prototype system demonstrates approximately 13 sensors spanning 40 m in a vertical array. Data is time-tagged by a microcontroller collocated at each sensor and then time-division multiplexed up to CMOS (complementary metal oxide semiconductor) memory in a buoy. The buoy is submerged until the data collection phase is complete. The array then rises to the surface and transfers data via a commercial spread-spectrum radio.

The sensors are connected by a cable containing three electrical conductors (30 AWG copper wire) and a kevlar strength member. The breaking strength of this cable is about 75 pounds (300 N). At the top of the cable the buoy, which remains below the sea surface during the data collection phase. The depth of this buoy

depends on the water current magnitude, but is usually 10 m or greater. An ABES array contains 10 CTDs, a current meter, pressure and tilt sensors.

Possible long-term applications for the outcome of this work include the monitoring of sewage outfalls, oceanographic fronts around offshore oil platforms, river estuaries, power plant discharge, mine reconnaissance and pre-surveillance for amphibious operations. There may be some commercial applicability as an alternative to expensive and relatively cumbersome systems now being marketed. Networks of deployable VLAs could be linked as a wireless undersea wide-area network using inexpensive, low-power acoustic modems communicating to a master buoy equipped with a satellite RF link.

Thermohaline structures of the Adriatic Sea acquired by the towed CTD chain

J. Sellschopp[1], H.-V. Fiekas[2], S. Podewski[2] and K. Herbig[2,3]

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During the military oceanographic survey Rapid Response 97, RV Planet spent a few days in the northern Adriatic Sea for rapid assessment of the mine hunting conditions in a 50 by 10 km area some 50 km SE of Venice. Among the important parameters to be measured were the temperature and salinity stratification and its spatial variability. Standard CTD casts were supplemented by high resolution measurements with a towed CTD chain. In the following, the CTD chain will be described and measurement results from the Adriatic Sea presented.

The CTD chain is, by its design philosophy, especially adapted for measurements in shallow water such as the Adriatic Sea. It can, by partial deployment, match the water depth. The total aperture and the distance between sensors can be adjusted prior to deployment. This is made possible by sensor fins using inductive coupling to the tow cable instead of underwater connectors. Sensor fins are autonomous CTD packages with platinum thermometers, multi-electrode conductivity cells and piezo-resistive pressure transducers. They transmit a data cycle after reception of their individual eight-bit address. With the data rate of 9600 Baud transmitted and received through the deck unit, a complete poll of all sensors takes two or three seconds for a chain equipped with 50 to 100 sensor fins. A standard PC is used for data acquisition and on-line viewing.

Several parallel CTD chain tracks were crossing the southern boundary of the cyclonic eddy in the northern Adriatic Sea. Upwelling in the surface jet at the front finds even more manifestation in the salinity field than in temperature. On the westernmost track, two different water masses meet at the eddy. The salinity in the surface layer changes by more than 0.5 psu within one second (3 m distance). On the next track to the east, the water masses have undergone some mixing already. Here the salinity increases gradually over a more than 5 minute period (1 km distance). The example demonstrates the appropriateness of the CTD chain for small scale mixing studies at sea.

HF Coastal Radar: Potentiality in marine coastal, surface current measurements

G. Dallaporta

CNR-ISDGM, Venice, Italy

The HF coastal radar (CODAR), using sea echo, from surface waves of electromagnetic waves emitted, allows to map marine coastal surface currents from ground stations. Actually, with radar systems that work in the frequencies between 10 and 50 MHz, it is possible to obtain spatial resolutions of 1 km and distances up to 50 km.

The CODAR system described here was installed to measure surface currents in the central Adriatic Sea, off the coast of Monte Conero in The Marches, Italy, working uninterrupted from October, 1997.

With opportune calibration and processing of data, the HF radar is capable of monitoring wide areas that would really be difficult or impossible to control with other systems, and could therefore replace conventional field measurements in collecting oceanographic data needed to map currents.

Physical control of the interannual memory affecting the biological response of the Northern Adriatic: Is it significant and how might we monitor it?

T. S. Hopkins

MEAS/NCSU, Raleigh, NC, USA

This presentation discusses both the hypothesis that the marine environmental conditions important to biological production of the Northern Adriatic can have a significant interannual memory and how this hypothesis might be confirmed and monitored. The environmental conditions primarily concern the storage with in the system of fresh water, of inorganic nutrients and organic matter in the water, and of organic matter deposited on the sediment interface. The degree of the storage retention in the system depends directly on the processes of water-mass flushing, sediment resuspension, and the vertical convection, all of which are forced by atmospheric exchange of water heat and momentum. The storage itself depends on the degree of nutrient loading and on the biological response to that loading, including both its quantity and structure. The degree of interannual coupling is determined at some point in the winter when the physical processes affecting the flushing are maximum and the incident radiation necessary primary production is minimum. The former dominates and is particularly sensitive to climate trends.

The assimilation capacity of the Northern Adriatic depends critically on its usual double thermohaline circulation: both an export of low density water and of a high density water. Both of these exports require the import of replacement water that provides vigor to its circulation and flushing. When these circulations have minimal overlap, the circulation and flushing of the system is maximized and vice versa. When seasonal flushing is vigorous, the carryover of mass and information is minimal, the seasonal initial condition for the biology varies less and the annual response is more predictable. Recent trends indicate the contrary situation making prediction difficult. An intelligent monitoring of the atmospheric forcing, of mass storages and their exports, and of biological structure arguably constitutes an essential condition for understanding and managing the Northern Adriatic resource.

A Systemic Approach to the Study of the Physiology of the Adriatic Sea

G. Civitarese

CNR - Istituto Talassografico, Trieste, Italy

Due to its physiography, water circulation regime and biogeochemical processes, the Adriatic Sea is a site in which integrated studies on the exchange of water and dissolved and particulate matter are particularly important. Such studies can be useful performed estimating the fluxes through critical sections. Furthermore, the correct estimate of the time variability of the exchanges permits to correlate the response of the basin to the physical and biological forcing, providing a first tool for previsional studies. This so-called systemic approach allows us to better understand the general physical and biogeochemical behavior of closed and semi-closed basins, and to possibly indicate the direction of more process-oriented studies and future actions. Recent investigations on water and biogeochemical budgets through one section in the Strait of Otranto (Southern Adriatic) show that the Adriatic Sea, on the whole, can be considered a site of mineralization of the organic N imported from the adjacent Ionian Sea. In addition, even if the Northern Adriatic signal can be recognizable from hydrological properties distribution, a deeper analysis of the outflows from the strait suggests that the Adriatic, on the whole, behaves like an oligotrophic sea, in terms of new production/total production ratio. The behavior of the northernmost sub-basin, the Northern Adriatic, is strongly seasonally modulated: in the productive season the basin produces organic materials entrapping all the terrestrial and atmospheric inorganic inputs and exporting mainly organic substances; in winter, a large net export of inorganic nutrients is noticeable, suggesting the presence of mineralization processes. The water exchange is stronger in winter than in summer. In any case, the eutrophic signal is too weak to influence significantly the trophism of the entire Adriatic Sea. Moreover, the removal processes of N (denitrification) and P (burial in the sediment) occurring within the northern basin reduce the nutrients availability for the advective export. The present communication is based on the most recent results obtained from the EU-OTRANTO and the national PRISMA-1 projects.

Circulation and transport of nutrients and inorganic carbon in the Northern Adriatic Sea.

E. Souvermezoglou and E. Krasakopoulou

National Centre for Marine Research (NCMR), Athens, Greece

The distribution of nutrients and inorganic carbon for the upper and lower layers in the Northern Adriatic Sea, is discussed in relation to the freshwater discharge, the chemical composition and the circulation of the different water masses in the area. The influence of the thermal stratification is examined by comparing the distribution of these parameters during stratified periods and periods of vertical homogeneity. The nutrient and carbon ratios are examined and interpreted in the "old" bottom layer under conditions of column stratification.

"Adriatic Ingressions" and Southern Adriatic Upwelling

I. Marasovic, D. Vilibic and I. Nincevic

Institute of oceanography and fisheries, Split, Croatia

Buljan (1953), as well as many other authors believe that Mediterranean waters transport an increased quantity of nutrients into the Adriatic, which in turn, causes increased productivity. Our results suggest another possibility, one which could prove to be more credible due to the fact that waters from the Ionian Sea and Eastern Mediterranean are extremely poor in nutrients and have low levels of productivity (Becacos-Kontos, 1977; Berman et al., 1984; Azov, 1986; Kimor & Wood, 1975; Kimor et al., 1987). These waters cannot affect an increase in productivity of the South Adriatic waters by enrichment through "alochtonous" nutrients, but they can strengthen upwelling due to their stronger inflow. Upwelling and/or mixing, brings the "autochtonous" South Adriatic nutrients from the deeper layers into the euphotic layer.

New Tiles for the Adriatic Mosaic

M. Ribera d'Alcala' and V. Saggiomo

Laboratorio di Oceanografia Biologica, Stazione Zoologica "A. Dohrn", Naples, Italy

The Adriatic Sea has received extensive attention in the last decades because of a clear increase in eutrophication in its northern part. Though, the central and southern part of the basin are highly oligotrophic. From this picture it seems that the general physiognomy of the basin is somehow contradictory.

The extent of coupling between the two subsystems has been the main focus of the Italian PRISMA project, even though one of the conclusions of the ELNA project, based on the fresh water budget, suggests a very weak coupling in term of fluxes.

To date, significant information has been gathered on the variability of biomass distribution and on the role of external forcing, both physical and biogeochemical, in regulating circulation and transports. Researches carried out in the Adriatic Sea so far have been mainly focused on the eutrophism-distrophism dipole. Most of the critical processes characterizing the basin (eutrophication, mucillagini formation etc.) are approached from the point of view of a disequilibrium in fluxes of basic components, generally attributed to peculiar dynamics in forcing factors. Because of this, relevant biological processes might have been overlooked.

The aim of this presentation is to comment on problems that have been disregarded, but that are worth studying in the peculiar Adriatic ecosystem and to discuss from different viewpoints on aspects that could add insights about biota responses. More specifically we will report on topics that have been addressed recently in the scientific literature such as life cycles of unicellular autotrophic organisms and their interaction with the bloom dynamics, alternative hypotheses on the role of extracellular exudates,
importance of jellyfish in marine environment etc. Our goal is to stimulate reflections on relevant gaps in our knowledge and understanding of the Adriatic Ecosystem.

Remineralisation of Biogenic Debris in Adriatic Sediments and Associated Sediment-Water Fluxes.

Willem Helder[1], Erica Koning[1], Paola Giordani[2] and Giuseppe Civitarese[3]

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[2] Instituto per la Geologia Marina - CNR,Bologna, Italy
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Benthic remineralisation rates of organic C, N and of biogenic Si and the associated fluxes of dissolved constiuents between water and sediment (oxygen, nitrate, and silicate) were quantified to:
-determine spatial and temporal variation of remineralisation rates and benthic fluxes within the Adriatic Sea.
-relate benthic regeneration with primary production of organic C and biogenic Si
-develop relationships between waterdepth and magnitude of benthic fluxes for the Adriatic Sea.
-assess the role of the Adriatic sediments in modification of chemical signals in Adriatic and Mediterranean deep water.

Benthic fluxes were derived from:
- pore-water profiles gained by extraction and shipboard analyses of pore water from boxcores/multicores.
- deck incubations of cores and overlying bottom water.
- in-situ incubations of benthic chambers (lander deployments).

Organic carbon mineralisation rates were estimated both from oxygen consumption (SOD) during in-situ incubations of benthic chambers and from modelling of high resolution porewater profiles of oxygen gained from in-situ micro-electrode measurements (lander deployments).

The field work was carried out during two cruises (EU-MATER) in August '97 and March'98) with RV URANIA in the Pomo Pit, the Southern Adriatic Basin, and the Ionian Sea at stations with waterdepths between 250 and 2350 m. Data from the shallow, river Po influenced, northern Adriatic were derived from an earlier EU-STEP programme with cruises (RV URANIA) executed in March '92 and August '93.

Results indicate that sedimentary oxygen consumption rates (SOD) decrease systematically going from the shallow Po-delta to the deeper southern Adriatic and Ionian Sea. Based on the in-situ micro-electrode measurements it could be indicated that SOD values are significantly higher in August compared to March, indicating higher input of degradable organic matter in August. Based on the SOD

values, and assuming Redfield stoichiometry, it can be derived that in the shallow northern Adriatic in March 10-20 % of the daily averaged primary production is mineralised in the sediment, while in August this amounts to 27- 50 %, indicating a tight benthic-pelagic coupling.

Diss. Si fluxes are, as the SOD's, clearly depth dependent and range from about 5-0.2 mmol m^{-2} d^{-1} going from the Po-delta towards the Ionian Sea. In contrast to the SOD's, diss.Si fluxes have no distinct seasonal trend. From the sum of diss. Si effluxes and burial rates of biogenic Si in sediments from the southern Adriatic it can be derived that > 20 % of the organic carbon arriving at the seafloor is derived from diatom production in surface waters.

Nitrate effluxes have a less clear depth dependancy and no significant seasonal trend. They range from about 4 - < 0.1 mol m^{-2} d^{-1}.

Downward Fluxes of Particulate Carbon, Nitrogen and Phosphorus in the northwestern Adriatic Sea

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In the framework of the PRISMA1 project annual variations of downward particulate fluxes were measured by sediment traps in the northwestern Adriatic Sea in two coastal stations 20 meter deep and one off-shore station 30 meter deep. The traps were placed at 2 different depths 2 m above the sealer and in the intermediate layer. Total fluxes, organic and inorganic carbon, nitrogen and phosphorus concentrations, mineralogical composition and particle size distribution were determined in the settled particulate, in the suspended matter and in the bottom sediments. Current velocity and direction were also recorded in the 3 sites over one year at the same traps depth. The obtained results were analyzed in relation to biological, physical and hydrodynamical factors (primary production, wave height, wind strength and river discharge), in order to discriminate the contributions of resuspension events, lateral advection and autochthonous production to the particulate total mass flux.

The coastal stations resulted directly influenced by the Po and Adige riverine discharge, as testified by their silicoclastic and carbonatic mineralogical compositions respectively, and by resuspension due to strong hydrodynamic events.

At bottom the measured mass fluxes resulted higher in the coastal stations, on average about 30 g m^{-2} d^{-1} with 2.5% organic C fraction, but highly time-variable. Fluxes were lower in the off-shore station, about 6 g m^{-2} d^{-1} and showed a higher organic fraction concentration (4 % organic C). At the intermediate depth, fluxes were strongly influenced, by the biological production, showing high values of organic C concentration (13 % in off-shore station), and by riverine discharge at coastal stations. Fluxes at bottom, were generally higher than at intermediate depths due to resuspension, particularly during winter, when the hydrodynamical situation was more active.

The export of C, N and P from the upper water column to the bottom compared with primary production was estimated over the four different seasonal conditions. From spring to autumn, C export ranged from 3 % to 20 %. During winter advective transport and resuspension events connected with mechanical mixing near the

bottom, produced C fluxes sometimes higher at bottom than primary production at surface.

The average C:N:P ratios in the bottom traps matter showed a marked difference between the two coastal stations and the offshore one. A high depletion of phosphorus and to a minor extent of nitrogen was evident in the offshore station. A relative accumulation of phosphorus in the sediment, mainly in the inorganic form, was evident and relevant at the coastal stations, by comparing the C:N:P ratios in suspended matter and in bottom sediments.

The Study of Geochemical and Sedimentological Processes in the Northern Adriatic Coastal Environment: History and Main Results.

F. Frascari, M. Frignani, M. Ravaioli, F. Alvisi, M. Marcaccio, G. Matteucci and C. Bergamini.

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The geochemical and sedimentological study of the Adriatic coastal environment began in the seventies under the pressure of marine pollution problems and distrophic emergencies. Nutrients and pollutants associated with sedimentary particles were the object of the first researches. At that time, however, these studies were lacking information on the physical, chemical, geochemical and biological natural processes in which the chemical species of interest were involved. One of the leading ideas of those studies derived from the concept that the surficial sediment preserves a time-integrated information and thus it could be analyzed to understand how the pollutant is dispersed after its delivery to the marine environment, where it accumulates and which is in relationship with the bulk composition of the sediment and its dynamics. A number of scientific papers have highlighted the role of the Po River and other minor fluvial inputs on the sediment pollution by heavy metal, polychlorinated hydrocarbons and nutrients. Complementary researches were devoted to the integration of the knowledge about distribution of chemicals. The studies of the composition of the sediment (mineralogy, geochemistry), the links between major and minor elements, the role of organic matter, all contributed to place contamination in the context of the natural processes and thus to evaluate and quantify their different aspects.

The study of the concentration-depth profiles in the sediment column and/or in the interstitial water and the quantification of the accumulation rates using radioactive tracers allowed the overcoming of the purely descriptive phase of the research: the new aim was to evaluate the diagenetic processes and to quantify fluxes and rates. The analysis of the sedimentary record showed that it was possible to get information about the time-trend of biochemical processes and pollutant inputs, even if concentration factors were never too high. The research devoted to the determination of the sediment accumulation rates was integrated by the estimate of the fluvial yield to calculate a crude mass balance of the sedimentary material and of the reactive species.

A further primary aim of this kind of study was to understand the contribution of the sea floor to the trophic status of the coastal areas, due to the release of nutrients in particular conditions. Therefore, the analysis of nutrient fluxes across the sediment/water interface considered several environmental conditions and different techniques. Benthic chambers, incubated cores and profiles measured in the interstitial waters were used. Nutrient exchanges during sediment

resuspension were studied through laboratory simulation experiments. The transfer of material through the water column were investigated using sediment traps and the disequilibrium 238U/234Th and 210Pb/210Po. The latter was used to determine the cynetic of the interactions between dissolved and particulate species and to discriminate between the role of the biogenic and the detritic particles. Moreover, very important experiments have been carried out by coupling sediment traps and automatic recording of water characteristics (e.g. turbidity). In this way, it was possible to separate the relative influences of the vertical sinking, lateral advection, primary productivity and resuspension of particles.

Presently, the effort is to give a contribution, through a benthic sub-model, to the trophic and ecological modeling of the Adriatic basin. Previous data and new results should be interpreted considering the coastal environment both as a filter, able to influence the transfer of material from the land to the deep sea, and as the site where human activity and natural processes are interacting. Furthermore, the coastal area is the location where climate changes impact very rapidly and where such changes could exert their most dangerous effects.

Sediment Accumulation Rates and Mass Balances in the Northern and Middle Adriatic: A Critical Review

S. Albertazzi, F. Alvisi, M. Frignani, L. Langone, M. Ravaioli and D. Sorgente

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The Adriatic shelf has been interested in the last decades by a series of problems and emergencies linked to the exploitation of its natural resources and the increasing input of agricoltural, industrial and urban sewages. Since most pollutants are characterized by a strong reactivity with particles and sediments can store the record of event and fluxes, an increasing number of studies were devoted to the understanding of the dynamics of modern sediment distribution and accumulation.

The knowledge of the rate of key processes driving the transport of mass and energy through the marine system is crucial for the assessment of the quantitative behaviour of the environment. Because of this, the determination of a large number of activity/depth profiles of radionuclides in sediment cores has been carried out in the last decade. The purpose was the calculation of sediment accumulation rates and particle mass balances in the Northern and Middle Adriatic sea.

The available rates, mostly derived from ^{210}Pb and ^{137}Cs distributions, will be critically reviewed in order to assess their accuracy since accumulation rate determinations can be severely biased by the effect of sediment mixing, either biological or physical. This will be done by a comparison of the distribution of inventories, the information provided by short lived tracers (^{234}Th, ^{7}Be), and available ^{14}C chronologies. The distribution of a conservative tracer, such as dolomite, can help to trace the dispersion of sediments supplied by the different sources.

Coupling sediment accumulation rates with an estimate of particle delivery from the rivers will allow the calculation of a mass budget with an estimate of the transfer of sedimentary material along the dispersal system toward the Southern Adriatic.

Presently, the calculated rates and mass budgets points out to the role of minor rivers, together with the Po River, in supplying sedimentary material to the Adriatic Sea, and confirm the importance of shelf processes of deposition and resuspension in determining its transport and fate. The results of the mass balance calculations show that a very significant transfer of material occurs from the Northern Adriatic area southward of the Conero promontory and then further south across Punta Penna. Nevertheless, the Conero shape induces a offshore shift

of the alongshore currents with a consequent eastward transport of the material coming from the north and at the same time creates a shaded area immediately south of it where we register an important increase of the accumulation rates probably due to local inputs.

Seasonal Particulate Organic Carbon Distribution in the Adriatic Sea (POSTER)

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The organic carbon concentration in suspended matter, along transects from the Po river delta to the Otranto Strait, in four consecutive seasonal conditions, are presented.

Particulate organic carbon (POC) data are correlated with other characteristics of particulate matter (total seston amount, number, volume and size spectra of particles, particulate nitrogen concentration, C/N ratio) to obtain information on the nature and origin of the suspended matter present in the different Adriatic areas.

The data permit a general view at the basin scale of organic carbon distribution and an evaluation of the time variations. The importance of biological production, riverine input and bottom sediment resuspension as carbon sources are pointed out.

Wedesday, 23 September

Sessions:

Modeling (comprehensive)

Modeling (specific)

Numerical Modeling of the Adriatic Sea Large Scale Circulation and Related Trophic Conditions: Seasonal and Interannual Variability

N. Pinardi, M. Zavatarelli, A. Maggiore and C. Cesarini

IMGA-CNR, Bologna, Italy

Recently the Adriatic Sea hydrological, dissolved nutrient and chlorophyll structure has been depicted on the basis of newly assembled historical data bases. The three dimensional structure and seasonal variability of the circulation has been redrawn on the basis of a modern analysis of a large climatological data set. The general circulation has been found to be formed by sub-basin gyres of different intensity and position during different seasons. The boundary currents on the Eastern and Western sides of the basin appear to be composed of jet segments which are seasonally modulated in amplitude. The Western Adriatic Coastal Current system emerges as a structure connected to the incomplete compensation between temperature and salinity signals coming from deep water formation events in the Northern Adriatic and the river runoff.

The study of the climatological atmospheric forcings and river run-off data over the basin reinforces the interpretation of buoyancy compensation effects even at the level of air-sea interaction budgets. The basin dissolved nutrient and chlorophyll climatological structure is also reconsidered in the light of a recently collected historical data set. The total nitrogen and phosphorous distributions indicate the importance of river nutrient inputs and the probable existence of phosphorous limitation to phytoplankton production in several sectors of the basin. Numerical modeling of the Adriatic Sea general circulation is presented and compared to the observational evidence. The large scale general circulation is simulated by the Princeton Ocean Model implemented in the Adriatic Sea with monthly mean climatological and interannual high frequency forcing. The major driving mechanisms of the circulation are in order of importance, the river runoff, the winds and the thermal fluxes. The mechanism of temperature and salinity compensation is then elucidated by conceptual experiments aimed to define the sensitivity of the Western Adriatic coastal current to single forcing functions. The effects of bottom stress and topography are also examined in isolation and found to determine the position of the Western Adriatic Coastal Current. Numerical simulations of the Adriatic Sea general circulation under interannually varying high frequency atmospheric forcing evidenced a large interannual variability in the circulation features and in the dense water formation processes occurring in the northern and southern Adriatic Sea.

Three-dimensional Finite-element Modeling of the Adriatic Sea

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The seasonal 3-D low frequency circulation in the Adriatic Sea is studied by numerically computing the circulation for six bimonthly periods (January-February, etc.). Forcing is considered from: the major semi-diurnal and diurnal tidal constituents (imposed at the Strait of Otranto); baroclinic pressure gradients (with temperature and salinity initialized from objectively analyzed climatological data); climatological estimates of the surface fluxes for heat, momentum, and salt; and climatological estimates of major river input and transport through the Strait of Otranto.

The Dartmouth Circulation Model is utilized for these studies. This free surface, 3-D circulation model includes tidal dynamics, wind and buoyancy driven flows, and the Mellor-Yamada level 2.5 turbulence closure scheme. The governing equations are solved using the finite-element method. In this study, our model domain extends over the entire Adriatic Sea with fine resolution (on the order of 1 km) in regions of particular interest (e.g., Po River discharge area and the Gulf of Trieste) and where the complex topography requires it (eastern coast and island chain).

The numerical results generally agree with the baroclinic geostrophic structure of the general circulation recently published by Dr. Antonio Artegiani and colleagues. In addition, the 3-D model results provide new information regarding the size, strength, and location of basin and sub-basin scale gyres and current structures. We also find favorable agreement between the trajectories of numerical drifters and recent observational drifter studies by Dr. Pierre-Marie Poulain. These model results can also be used in the selection of sites for future drifter releases.

At this stage, the model is ready for studies of events, such as Bora winds, sudden variations in the Po River discharge, and deep-water formation over the northern Adriatic slope and South Adriatic Pit. Preliminary results from event driven modeling studies may be included in the presentation, in addition to mature results from the aforementioned climatological study.

A Real-time Oceanographic Forecast System Covering the Adriatic Sea

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For several years the Naval Oceanographic Office has employed an oceanographic nowcast/forecast system for the Mediterranean Sea. The modeling system is used to make daily forecasts for all areas of the Mediterranean Sea, including the Adriatic Sea.

The modeling system is built around a version of the Princeton Ocean Circulation Model (POM) that is forced with forecast wind stresses and air-sea heat fluxes and includes a data-assimilation scheme fed with near-real-time temperature profiles and MCSSTs. This application of our modeling system is described in Horton et al. (1997).

We will use the modeling system to describe the seasonal variability of the Adriatic circulation from 1995 through the summer of 1998. In particular, we will show an extension of the inflow/outflow transports through the Strait of Otranto described in Horton et al. (1997) through the summer of 1998.

Another feature of our modeling system is the ability to nest higher resolution versions of POM within a 'host' domain. We are implementing a higher-resolution nest covering the Adriatic Sea within our 'host' Mediterranean domain. The horizontal resolution of the Adriatic nest is about 3 km, and we will describe preliminary results from these higher-resolution forecasts.

Simulation of the Adriatic Circulation Using Nested Models

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The circulation of the Adriatic Sea was investigated on seasonal and interannual time scales, using a one-way nested ocean model. The model for the Adriatic basin had a resolution of about 4 km, and the model for the Mediterranean Basin about 10 km. Both models had a vertical resolution of 41 levels.

The interface of the two models was at 40N in the Strait of Otranto. In one-way coupling, the coarse mesh solutions generally provide the appropriate boundary conditions for the fine mesh. In our studies, the normal boundary volume fluxes for the fine mesh were prescribed from those of the coarse mesh region. Other boundary fluxes for the fine mesh model were derived with up-wind advection schemes, from the coarse mesh for inflow and from interior points for the outflow. Coarse-mesh solutions were archived once a day for space- and time interpolations to the fine grid. The computations were carried out on both serial and parallel computers.

The initial conditions in the Adriatic were interpolated from the coarse mesh spun-up solutions (which includes the Adriatic). Initial hydrography for the large basin model was obtained from Levitus for some runs and from MODB for others. Atmospheric forcing was derived both from climatology (Hellermann-Rosenstein) and from daily GCM forecast products (US Navy NOGAPS fluxes).

The general circulation of the Adriatic shows the presence of two strong cyclonic gyres filling the southern and middle portions of the basin, whereas the northern third gyre of the basin shows strong variability depending on season and year. The northern circulation changed between cyclonic, anticyclonic and mixed motions. An examination of the flow details near the Strait of Otranto shows that much of the coastal transport along the Puglian coast gets recirculated and does not exit at the Strait; rather, there is a quasi-permanent eddy stationed in the Straits. Moreover, at times there are two depth intervals where flow is outgoing in some part of the Strait. The fine mesh Adriatic solutions also showed the presence of southbound coastal currents along the Dalmatian and Albanian coasts, which need more observational verification beside occasional drifter agreements.

The Effects of Bottom Topography on the Circulation in the Adriatic

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Topography plays an important role in controlling the circulation in the Adriatic. In particular, it appears that, in the vicinity of the Jabuka pit, there is a bifurcation of the eastern boundary flow resulting in an off-shore flow that crosses the Adriatic and joins the southward return flow on the western boundary. This effect shows up in satellite images and drifter data. To a certain extent this aspect of the circulation can be understood in terms of simple barotropic models. Results concerning this kind of bifurcation based on analytical models and numerical simulations of quasigeostrophic and shallow water models will be presented.

Medium-Term Coupled Meteo-Oceanic Prediction in the Adriatic Sea

P. Lionello and P. Malguzzi

A tri-modular model of the coupled atmosphere-sea system (called MIAO) has been developed and implemented in the Mediterranean region. The model consists of the meteorological limited area model BOLAM, the coastal ocean circulation model POM, and the ocean wave model WAM. The three models are coupled because the sea surface temperature computed by POM and the sea surface roughness computed by WAM are used by BOLAM which, in turn, computes the surface fluxes that force both POM and WAM. Consequently, the MIAO model computes the air-sea fluxes, accounting for the feedbacks of the sea on the atmosphere.

This study analyses the importance of these conclusions for the regional meteo-oceanic prediction in the Adriatic Sea, by discussing the results of coupled meteo-marine simulation carried out in a region including this basin.

The predicted quantities include both atmospheric variables (sea level pressure, winds, precipitation, air temperature, etc.) and oceanographic variables (sea level, sea temperature, currents, surface wave spectra, etc.). The feedback of the waves on the atmospheric flow is shown to be relevant for the prediction of the surface wind and therefore for the waves themselves and for the coastal surge. On the other hand, the effect of waves on the development of low pressure systems is generally small. The variations of the sea surface temperature are found to be relevant for the computation of low pressure systems (at least during fall, when the ocean mixed layer is shallow) and therefore for the evolution of the whole atmosphere-ocean system.

Interdisciplinary Multiscale Forecasting System for the Adriatic

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The accurate estimation of physical-acoustical-optical-biological -geochemical four dimensional fields in the ocean is now essential and feasible for modern ocean science and technology. The concept of integrated multidisciplinary ocean observing and predicting systems is explored. These systems provide an integrated ensemble of observations and data driven simulations. Observational strategies, long term and adaptive in the field, are fed by error estimation and evaluation of objectives generated by simulations. The simulations are generated by melding dynamics and observations via the assimilation of measurements into numerical models. The Harvard Ocean Prediction System is a flexible, portable and generic system for nowcasting, forecasting and simulations. Recent developments in HOPS and recent results from the application of HOPS in various environments, including the Ionian Sea and the Gulf of Cadiz are presented. An approach to a regional forecast system for the Adriatic, and some initial numerical simulations in the region are discussed.

An Overview of the Studies of the Dynamics of the Gulf of Trieste - an Emphasis to Tides

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The Gulf of Trieste, located in the northernmost part of the Adriatic Sea, is a small (12 miles x 15.6 miles), shallow (20 m depth) gulf with a relatively wide opening (12 miles). As such, it is strongly influenced by the atmosphere (wind, precipitation, evaporation), by continuous riverine inflows (mainly the Isonzo River), by the circulation patterns existing in the northern Adriatic Sea, and by the tides, which are the strongest of the entire Mediterranean Sea. Tidal current amplitudes are on the order of 10 cm/s. During periods of calm weather, tides are the main source of motion.

Previous numerical simulations of tidal dynamics dealt with the leading semidiurnal (M2) component. For coastal engineering purposes, the hydrodynamics of the Gulf have also been numerically simulated under imposed winds in a steady direction and with sea-surface elevations (SSE's) taken from tide gauge records. All these models relied on SSE and depth-averaged velocity data or on estimates along the open boundary at the Gulf's entrance.

The Kelvin number (K = L/R = 0.46, where L is the width of the Gulf and R the barotropic Rossby radius of deformation) and the horizontal aspect ratio A = $(K^*omega/f)^2$, where omega is the angular frequency and f the Coriolis parameter; A = 0.11 for diurnal constituents, A = 0.44 for semidiurnal ones) indicate that transverse velocities cannot be ignored, and demand that the tidal dynamics need to be studied numerically. In order to achieve a better understanding of the Gulf of Trieste tidal dynamics, the TRIM 2D numerical model was implemented for the simulation of tides over the entire northern Adriatic basin.

The numerical model confirms the expected dynamics. It shows that the SSE in the Gulf of Trieste is always higher on the right-hand side of the flow, as is the case in the rest of the northern Adriatic. The velocity distribution follows the rhythm of a standing wave, being slightly modulated across the Gulf by the Coriolis force. At times of high inflow/outflow, the isolines of SSE are aligned with the transport velocity in the along-channel direction. Therefore, from the point of view of tidal dynamics, the Gulf of Trieste may be considered as a miniature of the

northern Adriatic Sea, decreased in size and rotated by about 90 degrees.

An Eddy -Resolving Numerical Study of the General Circulation and Deep Water Formation in the Adriatic

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We use an eddy resolving implementation of the Princeton Ocean Model (POM) to study the functioning of the Adriatic Sea with special emphasis on the water formation processes. The horizontal resolution is 5 Km, with 20 sigma layers in the vertical. In order to minimize open boundary effects, the model domain extends south of Otranto into the Ionian, down to a latitude of 37 N. The model is initialized with the MODB data set. Atmospheric forcing is provided from ECMWF data, covering the period 1979-1994, which have been processed to provide a 'perpetual year' data set. Heat fluxes are not imposed but rather computed interactively by the model with the use of appropriate bulk formulae. All major rivers along the Italian and Albanian coast as well as diffusive sources along Croatia have been included in the model.

After a one year spin up the model exhibits an almost repeated seasonal cycle. The mean annual heat budget is close to a loss of 25 W/m2. Evaporation minus precipitation is close to zero while river runoff is evaluated at 0.85 m/yr. In terms of buoyancy (with the equivalence of 1 m/yr to 13 W/m2), this means that the Adriatic has a net annual mean buoyancy loss.

The general circulation of the basin is found to be cyclonic, in agreement with measurements and previous numerical studies. Two major cyclones are found, one in the middle and one in the south Adriatic. Another important feature, is the narrow and shallow current which originates in the north and moves to the south along the continental shelf of the western Italian coast which undergoes an important seasonal variability.

An interesting feature found in this study is the existence of two cyclones in the South Adriatic. The external one covers the whole south Adriatic basin, while the smaller one is asymmetrically imbedded in the larger one, bounded by the 1000m isobath. The two cyclones share their eastern flow and are distinct at their western part. The bifurcation occurs at the northernmost edge of the two cyclones, where the topography drives the inner cyclone to the west. During winter the inner cyclone is the site of the 'open ocean' dense water formation, while the external gyre becomes unstable and a number of mesoscale anticyclonic eddies appear. The role of these eddies is anticipated to be important to the deep water formation process and will be further examined.

The dense waters formed in the northern Adriatic reach the middle Adriatic pit and from there move to the south as a vein of dense waters (sigma-t>29.4) along the Italian continental shelf at depth of approx. 75 m with lighter waters below. The journey of these waters ends up at the vicinity of Bari, where a topographic anomaly destabilizes the flow. After that point, the dense waters sink to the bottom filling the deepest parts of the southern Adriatic basin.

It seems therefore, that the dense waters exiting the Adriatic through the Otranto strait are made up of a mixture of dense waters formed through open ocean convection in the southern Adriatic and dense waters formed through continental shelf convection in the north. The relative contribution of each of the two mechanisms is still to be defined. The total amount of dense waters (sigma-t>29.15) exiting Otranto is found to be 0.35 Sv, in close agreement with previous independent estimates.

Modeling the Adriatic Sea Ecosystem Dynamics: From 1D to High Resolution 3D Models

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The Adriatic Sea ecosystem dynamics have been studied by using a coupled system constituted by a general circulation model (Princeton Ocean Model, POM) and a generic biomass based ecosystem model (European Regional Seas Ecosystem Model, ERSEM). Simulations with the POM/ERSEM system have been carried out by developing different and increasingly complex (from 1D to high resolution 3D) model set-ups. One dimensional simulations concerned the northern Adriatic Basin; the model was implemented at the same locations of the PRISMA-I Project sampling stations S1 and S3, the former characterized by strong river-runoff (Po river) conditions, while the latter has relatively open sea characteristics. The model results highlighted the yearly phytoplankton cycle and its relations with the external nutrient inputs, the seasonal mixing processes and light distribution in the water column. Moreover, the comparison between the two stations allowed for a definition of the role of the bacteria in controlling the carbon fluxes in the trophic web under different trophic conditions. As an intermediate step toward the 3D high resolution application, a coarse resolution 3D implementation with idealized basin geometry was developed. The model results relative to phytoplankton distribution are in good agreement with CZCS climatological satellite pictures of pigment distribution in the basin. Despite the coarse resolution and the idealized geometry, the model is able to reproduce and maintain the north to south trophic gradient characteristic of the Adriatic basin. The seasonal phytoplankton cycle in the northern, central and southern Adriatic sea appears to be strongly influenced by both the physical processes and the external, riverborne, nutrient input. Finally, experiments with an high resolution implementation show a more detailed temporal and spatial variability of the biogeochemical properties distribution, further emphasizing the importance of the circulation features in determining such variability. The dense water formation process in the northern Adriatic Sea is reproduced by the model and the resulting water mass show distinct properties also from a biogeochemical point of view.

Coupling Finite Element Hydrodynamical Model with Trophic Web: 1980 Winter Conditions in the North Adriatic

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The ecological evolution of the trophic levels of the Adriatic Sea is addressed in this work with a three-dimensional finite element hydrodynamical model coupled with a trophic food web. The finite element primitive equation model uses an implicit algorithm for the solution of the barotropic part, while the baroclinic variability is resolved explicitly. The grid covers the Adriatic Sea down to the Otranto Strait and therefore obviates for the need to specify boundary conditions close to the investigated area. The resolution of the grid is variable passing from 30 km in the central Adriatic Sea to about 2 km close to the Po delta. Wind stress for the year 1980 are interpolated every six hours at the appropriate grid points, and climatological values of temperature and salinity are imposed as initial conditions. Po inflows are daily discharge data for the whole period. The trophic food web is based on carbon cycle of phytoplankton, zooplankton and bacteria. Also inorganic, organic and detrital fraction of phosphorus are taken into account in the ecosystem evolution. As initial conditions typical winter values are considered for the biological variables and the inorganic, organic and detrital phosphorus concentrations in the Po river are taken fixed to the annual averages. Distributions are shown for the North Adriatic area and time series for the main variables are discussed.

A Realistic Simulation of Po River Outflow and West Adriatic Coastal Current

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The development of the Po River plume and the evolution of the related west Adriatic coastal current are simulated with the three-dimensional, free surface, sigma coordinate Princeton Ocean Model. The model grid is the same as in Kourafalou and Zavatarelli (1997), extending south of the Otranto Strait, with a curvilinear grid that allows fine horizontal resolution and detailed topography. The river induced stratification is based on a source term in the continuity equation; this parameterization can successfully represent the dynamics of the plume and coastal current that result from river input (Kourafalou et al., 1996).

Previous studies on the Po River plume with the same model (Kourafalou and Zavatarelli, 1997; Kourafalou, 1998) elucidated the role of buoyancy, wind stress and topography on the transport of Po waters and associated materials. It was shown that the trajectories of water particles released at the Po River mouth were largely influenced by the basin geometry and bathymetry, the amount of runoff and the magnitude and direction of wind stress. The present study extends those findings by employing realistic topography, daily varying discharge for the Po and 6-hourly varying wind stress (ECMWF data) to simulate two periods during 1994. The first period (January 1994) is representative of winter conditions, while the second period (November 1994) is characterized by low wind stress and an intense episode of high runoff. The model is initialized with the results of seasonal diagnostic runs, based on climatological data for the winter and autumn seasons, respectively (Artegiani et al., 1997). Model results are compared to data from the ELNA (Eutrophic Limits of the Northern Adriatic) project (Artegiani et al., 1998).

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A Case Study of Bora Wind Event in the Adriatic Sea Using a Coupled Ocean-Atmosphere Model

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A high resolution three-dimensional coupled ocean-atmosphere model is developed to simulate physical processes in the coastal zone. The model combines a three-dimensional primitive equation ocean model and a non-hydrostatic atmospheric model, coupled in a two way interaction. The atmospheric model is a limited area model with the horizontal resolution comparable to that of the ocean model, which uses initial and boundary conditions from global atmospheric model outputs.

A case study of a strong Bora wind event is presented showing the influence of the high variability in coastal topography around the Adriatic Sea on the local atmospheric forcing of the sea circulation. This study demonstrates that under these wind conditions only the use of such a high resolution coupled model allows to resolve realistically the high spatial and temporal variability of the atmospheric forcing and to predict realistic circulation in the Adriatic sea.

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Thursday, 24 September

Sessions:

Deep Water Formation & Climate Variability

Regional Oceanography

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Contrasting the "Driving Engines" of the Eastern Mediterranean Conveyor Belt: the Southern Adriatic Versus the Aegean Sea

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The Eastern Mediterranean sea is subject to a vertical, or thermohaline circulation similar to the conveyor belt of the global ocean. New deep water is formed where and when surface waters preconditioned by high salinity become sufficiently dense by cooling.

Hydrographic surveys since the 50's consistently showed that for the waters below 1,200 m over the entire basin the dominant source region was the Southern Adriatic sea. This was confirmed by the hydrographic survey POEM5-AS87 during which transient tracer distributions were measured. They showed that Adriatic Deep Water formed in the Southern Adriatic sea outflowed from the Otranto Strait from where it spread into the deep Ionian interior becoming Eastern Mediterranean Deep Water (EMDW), hence proceeding to the Levantine basin in the bottom layer. General upwelling to the deep and transitional layers provided the return pathway to the Southern Adriatic thus closing the thermohaline cell.

A successive transient tracer survey carried out in Winter 1995 as part of the POEM Levantine Intermediate Water Experiment showed a dramatic change in the source of the Eastern Mediterranean deep water. The engine of the deep thermohaline circulation was now the Aegean Sea, with denser water masses exiting from the Cretan Arc Straits, spreading throughout the basin and pushing to the west the less dense EMDW of Adriatic origin. This dramatic change in the Eastern Mediterranean deep circulation actually started in 1991, as the analysis of the POEM-BCO91 survey has revealed. Specifically, this analysis shows that all the water masses in the intermediate-transitional and deep layers were formed in 1991 in the Cretan/ Aegean sea. In 1987 the Levantine Intermediate Water (LIW) was formed in the proper Levantine basin and spread following a westbound pathway on the isopycnal horizons of 29.00-29.05 kg/m3. In 1991 LIW was replaced by Cretan Intermediate Water and EMDW was replaced by Cretan Deep Water. All the water masses on the isopycnal surfaces from 29.00 to 29.18 kg/m3 originated in the Cretan/Aegean sea. They spread to the deep Ionian interior there forming a closed inertial recirculation, as showed by the horizontal homogenization of temperature and salinity on these isopycnal horizons.

Interannual Air-Sea Heat Flux Variability and Deep Convection in the Southern Adriatic

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Heat loss from the sea-surface is one of the essential processes in generating deep convection, and consequently, the dense water formation. The area of the cyclonic gyre in the South Adriatic Pit has been recognized as a site where the Adriatic Deep Water has been forming. This occurs in three phases: preconditioning (during December), mixing (in January and/or February), and sinking and spreading (from March on). Daily net heat fluxes for December, January, February and March in the Southern Adriatic since 1979 is calculated using meteorological data from ECMWF at Reading. The interannual variability of the heat flux during these winter months may be analyzed through the total heat loss, integrating daily net fluxes in the time interval December-March for each winter. Thus obtained heat loss ranges from -3.66 10^8 J/m^2 (winter 1989/90) to -13.4 10^8 J/m^2 (winter 1991/92). Hence, the intensity of the convection and the hydrographic characteristics of a deep water formed should also vary from year to year. Indeed, in the last decade a noticeable variability has been observed in the winter density vertical pattern across the South Adriatic Pit. The two situations at the end of winter illustrate this large interannual variability: the large pool of homogenized water column in the South Adriatic Pit in April 1992 contrasts a low depth (about 400 m) and a much more limited convection area in March 1998. It turns out that the water found there in 1998 is less dense than in 1992, due to lower salinity. From satellite IR imagery, in 1998 the whole cyclonic gyre area seems also slightly warmer than the previous year. The regime of a lower deep water production rate, and its possible lower outflow rate across the Strait of Otranto might influence the general and sub-basin circulation in the Adriatic Sea, reducing the longitudinal water exchange. The reason for such a variability, however, seems to be not only in the heat flux variations associated to local climatic conditions, but also in the varying hydrographic conditions in the adjacent basins, especially in the Ionian Sea and in the Eastern Mediterranean. One of the main contributions to the Adriatic Deep Water comes from the inflowing Levantine Intermediate Water from the Ionian Sea. Its characteristics may be altered due to the recently observed changes in the deep circulation in the Ionian Sea, as a consequence of the Aegean contribution to the Eastern Mediterranean Deep Water.

Calculation of the heat and momentum fluxes over the Adriatic Sea

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Using the NCEP weather prediction model, heat and momentum fluxes were calculated for the Adriatic Sea. Actually in order to reduce the influence of the boundaries the integration region was much wider covering the entire Mediterranean and the eastern Atlantic. Four sets of fluxes were produced, two different situations and two different resolutions, for each situation. The lower resolution run was 1 by 1 deg while the higher was .5 by .5 deg. Situations were from March, representing winter and with a Bora episode. The other one was from July, as a representative of the summer SST's. The winter situation data were NCEP `s 1 by 1 deg analysis while for the July case data were from ECMWF MARS's archive with the same resolution. In both cases sea surface temperature were the climatology data from NCAR.

Hydrology and Circulation in the Southern Adriatic Sea in Winter 1996

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The Southern Adriatic Sea was visited during the winter 1996 cruise (17-28 February) carried out in the framework of the PRISMA (Programma di Ricerca e Sperimentazione del Mare Adriatico) longitudinal flux studies. The hydrological stations were located along cross sections over the Pelagosa sill (200 m) and at the Otranto Strait, where the topography reaches the 800 m depth, with the aim of investigating the transport of major water masses which affect the general circulation in the southern portion of the Adriatic Sea and at the opening communicating with the Ionian Sea. The large topographic depression inside this region, down to about 1200 m depth (the Southern Adriatic Pit), was investigated as well.

A large multi-lobe cyclonic gyre, marked at the surface by the 29.10 kg m^{-3} isopycnal, occupied the zonal area delimited by the 17°-18.5° longitude E and the 41.5°- 42.5° latitude N. The gyre was elongated toward the north shelf-break area and in the center of the topographic depression, where apparently it was intensified by the outcropping of the 29.15 kg m^{-3} isopycnal, favoring the exposure to the surface of high salinity water ($S > 38.65$) upwelled from the intermediate layer. Low temperature values ($\theta < 13.4$ °C) provided the necessary condition of dense water formation and consequently deep convective movement in the centre of the gyre after intense outbreak of cold and dry northerly wind events.

Detailed examination of some CTD stations inside this region performed at the initial phase of the cruise shows that the oxygen-rich water column was well mixed from the surface down to a depth of 400 m, indicating that previous storms had already contributed to deep convective movements prior to the survey. The potential density excess at the surface was in the range between 29.15 and 29.16 kg m^{-3} providing one of the most important factors for the overturning events. Combined analysis of time series of meteorological parameters in the centre of the studied region, derived from ECMWF model, shows a repetition of heat loss events of about 300-350 W m^{-2}, which are consistent with what we could expected from the buoyancy loss computed from CTD data collected during the previous autumn cruise. It had occurred most likely during the December-January events.

Subsequently, CTD stations, obtained 9 days after an intervening period of relatively strong atmospheric forcing which occurred during the cruise, show a changing in the hydrographic structure within the convective zone. An

intensification of baroclinic cyclonic circulation was accompanied by the increase of the thickness of the oxygen-rich mixed water column down to a depth greater than 600 m. The oxygen minimum layer was established at 600 m depth in the centre of the gyre in combination with the deepening of the temperature and salinity inflection point. At the same time, oxygen-rich water masses from the surface slid down along the 29.16 doming isopycnal to fill the deep layer also below the surface lighter water on the border of the gyre.

Finally, the oxygen profiles show a sequence of relative maxima beneath the oxygen minimum layer in the depth between the 800 and 1000 m, suggesting that the deep water had been recently ventilated. The renewal time of the water content in between this layer of about 240 days is consistent with the most recently estimated water transport across the Otranto Strait which indicates an increase of the flow during the spring, while a weaker flow is documented during the autumn.

Long Term changes in the Adriatic

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The main cause of long-term changes in the Adriatic is the periodic inflow of Mediterranean waters into the Adriatic and the zonal horizontal air pressure gradient over the area. These changes are related, and reflect global changes.

The advection of Mediterranean waters is not only limited to the southern Adriatic but influences the northern Adriatic as well. Advection of the saltier water from the Mediterranean into the Adriatic causes changes in thermohaline properties, which has been demonstrated in both recent and earlier studies, along the Split-Gargano transect in the middle Adriatic.

Both oceanographic and meteorological parameters in this region show trends and periodic fluctuations as well. Long-term changes of a number of parameters will be shown and their interrelations discussed.

The periodically stronger Mediterranean inflow brings nutrient richer water into the Adriatic which causes fluctuations of some biological parameters like the chlorophyll a production.

Variability of the LIW Flow Patterns in the Adriatic Sea in the last 40 Years

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A complete hydrographic data-set, obtained merging the historical data (MODB data) with more recent CTD data collected during the 90's, was used to investigate the thermohaline characteristics of the Adriatic Sea general circulation at different levels. The analyzed data-set covers the years 1911-1914 and 1947-1996 with more than 10.000 stations, regularly distributed in the four seasons. The climatological analysis of the thermohaline fields on vertical sections and horizontal maps was used to evidence the seasonal variability of the Levantine Intermediate Water (LIW) flow patterns. It forms in the Eastern Mediterranean during winter and spreads westward in a few hundreds meters depth feeding the salinity maximum layer present throughout the Mediterranean. One branch moves northward toward the Adriatic Sea (Wüst, 1961) while the main core flows through the Strait of Sicily constituting the main source of high saline waters in the western Mediterranean Sea and even in the N Atlantic. For its thermohaline characteristics, the LIW serves as water preconditioned to form denser waters by convective mixing to great depths (Pollak, 1951; Wüst, 1961) in favorable regions such as the Southern Adriatic Sea (Ovchinnikov, 1985) and in the Gulf of Lion (Rhein, 1995). At the Otranto Strait, LIW temperature and salinity values near the core (ca. 300 m) are $T \sim 14.2\ ^{o}C$ and $S \sim 38.75$, values which are lower than at the formation site because of continuous loss of heat and salt by mixing. The climatological horizontal maps of salinity maximum, obtained using the Objective Analysis technique, evidence a strong seasonal signal. The LIW core presents its maximum extension and its higher values in autumn, with salinity $S > 38.80$ at the entrance of the Otranto Strait, and $S > 38.75$ in the Southern Basin. In autumn but also in summer values of salinity $S > 38.65$ were found in the Middle Adriatic Pit, evidencing a tail of LIW protruding more diluted toward this area. In winter it presents the minimum extension.

Finally, the time series of the temperature, salinity and density yearly mean values have been calculated for the last 40 years considering all the hydrographic profiles with depth greater than 600m (i.e. in the Southern Adriatic Pit). An interannual variability of the LIW, evidenced by salinity values greater then 38.70 below 100 m of depth, was detected and linked up to climatic changes.

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Cold Adriatic Surface Water in subsurface lenses observed in the central Ionian Sea

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Two lenses of cold water with core temperature 12.5°C were observed in autumn 1996 in the central Ionian Sea on the occasion of an ocean acoustics experiment. They were filling the depth interval from 200 to 400 m between the thermocline and the maximum salinity layer of Levantine Intermediate Water. In the course of 8 days, numerous expendable bathythermographs and sound velocitymeters were deployed in and outside of the cold water patches, the diameters of which were determined to be only 15 nautical miles. By combination of measured temperature and sound velocity profiles, a salinity of 37.8 psu was calculated in the lenses. Horizontal pressure gradients caused by their low density must be geostrophically balanced by anticyclonic rotation of the lenses.

During a detailed oceanographic survey in 1997, an equally small but less cold lens was found in the western Ionian Sea. This time, accurate CTD probes were used and supplemented by direct current measurements. The salinity and density in the lens of 1997 are consistent with the estimates made for the 1996 lenses. It was indeed observed to rotate as an anticyclone.

The surface of the central Ionian Sea never cools down below 13°C. Therefore the cold lenses must have been advected. Their most probable origin is the Adriatic Sea, where surface water with sufficiently low temperature and salinity is available in winter and may be subducted under the Ionian Surface Water by isopycnic intrusion. Anticyclonic subsurface eddies may be created and pinched off by a mechanism similar to meddy generation. Another possible source of the cold lenses may be the shallow Tunisian shelf where in February 1996, different from other years, the Modified Atlantic Water was cooled down to 12°C.

There are three possible explanation for the fact that similar cold water lenses in the Ionian Sea have never been reported before. They may not have been present before 1996, or they were missed by the coarse horizontal resolution of oceanographic surveys, or isolated measurements exposing this unusual water mass were not trusted.

Solar Heating of the Sea Surface in the Apulian Shallow Waters

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We have measured deltaO-18 in Globigerinoides Ruber of a shallow Ionian sea core, in order to provide a reliable record for the solar irradiance heating of the sea surface in the last millennium. The core was dated with great accuracy (1%) using radiometric and thephroanalysis techniques. By analyzing the time series with different spectral methods (such as the method of superposition of epochs, the singular spectrum analysis and the maximum entropy method), we have evidenciated in particular the presence of a statistically significant oscillation with period of 11.4 years. The amplitude of this component (0.07 per mil) gives an estimate of the sea surface temperature variation of about 0.3 K, which corresponds to one per mil of the average temperature of the sea: This is in agreement with the variation of the total solar irradiance output measured in space during the last solar cycle. The present result obtained over the last 800 years demonstrates that the the sea surface temperature is forced by solar output variations.

Adriatic Sea: Spatial variability of the basin-wide circulation, longshore water fluxes and exchange with the Ionian Sea

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The Adriatic Sea can be divided into three sub-basins distinct from the point of view of their oceanographic characteristics and bathymetric features. The northern part is a shallow shelf area with a gently sloping bottom down to the 100 m isobath at its southern limit. The central part encounters the Middle Adriatic Pit; a circular 270 m deep area delimited at its southern edge by the 170 m deep Palagruza Sill. Finally, the South Adriatic Pit is roughly of a circular shape and the deepest portion of the Adriatic Sea (maximum depth about 1200 m). It is delimited to the south by the 750 m deep Sill of Otranto and towards the coasts by narrow smooth shelves. The freshwater discharge in the Adriatic is rather high (up to 5700 m^3/s), and more than 50% of that discharge is concentrated in the northern shallow part.

The circulation in the Adriatic is forced by the longitudinal pressure gradient caused by the freshwater contributions to the northern shallow part as well as by the differential cooling/heating of the water column during winter/summer (the heat losses/gains in the northern part of the Adriatic are larger than in the Middle and South Adriatic). During the winter, dense water is formed in both the northern shelf area and in the South Adriatic Pit. The Northern Adriatic shelf area is a source of two water masses one relatively fresh in the surface layer due to the influence of the riverine inflow, and the other cold and dense formed in the winter, which occupies the bottom layer. The southward spreading of these two water masses, occurs in the form of a narrow swift surface coastal current along the Italian shore of a width of the order of 10 kilometers, and in the form of the bottom density driven current, respectively. The much wider compensating inflow occurs along the eastern coast. This transversal asymmetry is possible since the width of the Adriatic Sea is about 200 km, i.e. an order of magnitude larger than the maximum value of the internal Rossby radius of deformation.

Recent estimates of the southward water fluxes have indicated that the Northern Adriatic adds to the South Adriatic Pit only 3-4% of the total water volume exchanged through the Strait of Otranto. Also, it was shown that at the Palagruza Sill, the northern border of the South Adriatic Pit, about 75% of the water entering through the Strait of Otranto recirculates. Thus, the Palagruza Sill represents a discontinuity area separating relatively shallow and productive northern shelf from the oligotrophic South Adriatic Pit.

In interpreting these results one should however bear in mind that these flux

estimates are obtained on the basis of a single year realization, and on the other hand, it is well known that the year-to-year variations of the oceanographic conditions in the Adriatic are rather large. Consequently, the longitudinal fluxes, as well as the exchange with the Ionian Sea are subject to strong interannual variations. Thus, one should assess whether these conclusions are obtained for extreme conditions of the longitudinal exchange or they are representative of the average conditions. As mentioned earlier, the most important driving force of the longitudinal fluxes is the pressure gradient which is to a large extent dependent on the buoyancy input and, during the winter, on the magnitude of the surface heat losses and subsequent dense water formation. Therefore, climatic conditions of the specific year for which fluxes have been assessed, have to be compared with the long-term climate characteristics.

Observing and Modeling Physical Processes in Croatian Coastal Waters

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Various physical phenomena which occur in the east Adriatic coastal waters are reviewed first. The presentation then focuses on wind-related variability and on some of its specific aspects as observed and modeled in Croatian coastal basins. Thus, direct response to the Bora wind forcing is illustrated by data originating from the Rijeka Bay. It is shown that inshore dynamics are dominated by the bottom-slope effect - unlike the open Adriatic processes which are subject to the wind-curl control. Surface seiches are then described on the basis of pressure tide-gauge measurements recently carried out in the Lim Channel. Comparison with the concurrent meteorological data shows that the seiches tend to be generated locally. Finally, internal Kelvin waves are documented from measurements performed lately at seven current-meter stations in the Zadar and Pasman Channels. Decay of the waves is interpreted in terms of energy leaking through a sound which is positioned at the head of the basin.

The Second Mesoscale Experiment in the Pomo Pits (Middle Adriatic Sea, May-June 1993)

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In September 1989 the Adriatic Mesoscale Experiment (AMEX) was carried out in the Pomo (or Jakuba) Pits, a system of depressions (maximum depth 270 m) located on the continental shelf of the Middle Adriatic Sea. This experiment revealed for the fist time the Middle Adriatic mesoscale eddy field (Paschini et al., 1993). Two oceanographic cruises were executed in May and June 1993 in the same area to examine the spring mesoscale eddy field and its evolution, sampling involved also some biogeochemical properties. During the first cruise, 77 CTD casts were performed, including dissolved oxygen measurements, in about two days; 38 casts involved also biogeochemical sampling, and 74 XBTs were launched. During the second cruise, 87 CTD cast were performed, 45 included biogeochemical sampling, and 99 XBTs were launched, in about 3 days. With respect to the autumn 1989 experiment, the mesoscale was not fully resolved, due to the combined effect of the coarser sampling adopted and of the reduced internal Rossby radius of deformation. However, interesting phenomena were observed. For instance, during the May cruise, a cold and dense water mass (Northern Adriatic Deep Water, NAdDW) was entering the Pits, flowing on the bottom and rotating cyclonically around them; in June, the bottom layer of the Pits was found partly filled by this water mass. Dissolved oxygen and nitrate data add more information on this process, putting in evidence that mixing was active in May and part of the older bottom water had been displaced upward by the entering water. Correlation studies revealed a patchiness of the temperature field at 20 m and a larger scale coherence at 75 m, while the salinity field exhibits a broader coherence at the same depths; concerning dissolved oxygen, small scale correlation occurs, close to the spatial resolution of the survey. The Harvard Ocean Prediction System (HOPS) has been applied to simulate the mesoscale evolution from the first to the second survey, and results will be discussed.

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Sea Response of the Area of Brac Channel (Middle Adriatic) to an Extreme Sirocco Event in November 1996

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During 1996 intensive STD, current and sea level measurements were performed in the area of Brac Channel (east coast of the Middle Adriatic). Interesting dynamics were observed in November when an extremely strong Sirocco wind appeared. It blew for ten days (10-20 November) with a mean speed of about 12 m/s, with maximum hourly means up to 22 m/s. From the 20th of November to the end of the month, a very unstable synoptic situation remained, with few episodes of Sirocco and Bora wind. Residual sea level in the area was raised for almost 40 cm from the 1st to the 20th November, when strong Adriatic seiches (period of 22 h) with maximum amplitude of about 60 cm occurred. Temperature, salinity and sigma-t increased with depth, especially in the first ten meters. During the period of extreme Sirocco the temperature in the whole water column reached the constant value of about 18 C. Currents were directed by wind, but stronger in the bottom layer for 10-20 cm/s than in the surface layer. Thus, the increase of surface temperature and process of upwelling occurred, in contrary to expected Ekman transport and downwelling, probably as a result of circulation of neighboring Kastela Bay. After that, the cooling of the whole water column was in progress, faster in the surface layer, due to cold Bora influence.

Synthetic Tsunami mareograms for realistic oceanic models: Possible applications to the Adriatic region.

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The method that we developed allows us to calculate synthetic signals due to the tsunami mode, excited by a buried double-couple point source, propagating into an ocean, of variable thickness, fully coupled with the solid earth.

The cataloguing of the Tsunamis that occurred along the Italian coasts, demonstrates the relative high level of risk connected to the Tsunamis in the Adriatic sea. The inspection of the available earthquake catalogues allows us to identify the possible tsunamigenic areas in the proximity of the Adriatic region. Using the selected seismic sources, a database of synthetic signals can be easily constructed for a quick system of tsunami warning.

The calculated tsunami signals allow us to determine easily, for any source of interest, the maximum height of tsunami motion expected at different locations, taking into account the local variations of the sea bottom. These computations can, of course, be made before the event occurs, thus optimizing the efficiency of any warning system. Examples will be shown

Sea Level Changes in the Northern Adriatic

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Sea level fluctuations occur on various time scales and represent the effect of a number of different factors, including the gradual changes due to climatic warming and the more rapid response associated to atmospheric perturbations. The consequences of sea level rise can be particularly important, in terms of inundation, erosion and salt intrusion, for the low coastal areas, as is the case of the Northern Adriatic. The basin is shallow and semi-enclosed, and the sea level fluctuations are characterized by a significant astronomic tide component and other components, of the same order of magnitude, connected to the atmospheric forcing (storm surges, seiches). Persistent southerly winds over the Adriatic Sea and the transit of low pressure areas across the northern basin can induce significant sea level rise that, superimposed to unfavorable astronomic tide conditions, may severely affect human activities. The interannual and interdecadal evolution of sea level is studied by analyzing observations performed at various tide-gauge stations along the Adriatic coasts during several decades; the sea level evolution on shorter time scales is studied mainly from data measured at Trieste. Sea level fluctuations are examined together with the relevant atmospheric parameters, namely atmospheric pressure and wind. The occurrence of marked sea level rise events is studied as a function of time, in connection with the atmospheric forcing. Such analysis is applied both to the actual sea level elevation, and to the meteorological tide only, which accounts for the effect of atmospheric pressure and wind forcing on the sea level.

Optical seawater properties in the Gulf of Trieste

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The results of a set of underwater down and upwelling PAR irradiance vertical profiles performed in the Gulf of Trieste are presented and discussed. Absortion, backscattering and attenuation coefficients are computed; a correlation between the in situ irradiance and the conventional Secchi disc depth is found.

Sea level Measurements by Means of Acoustic and Laser Distance Meters

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An acoustic distance meter has been successfully used at the mareographic station of Trieste for many years : the calibration and data acquisition methods are presented. Recently, higher accuracy and temperature independent sea level data are currently obtained by means of a laser distance meter. The performances of these new instruments, coupled to common data loggers or PCs, are compared with the conventional stilling-well float operated tide gauge.

The activities of the Meteorology and Oceanography section of the Department of Earth Sciences, University of Trieste, and the characteristics of the meteorological and mareographic stations of Trieste will alsobe presented.